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INVESTIGATION OF VARIOUS FULL-SCALE PARACHUTES AT MACH NUMBER 3.0

David E. A. Reichenau

ARO, Inc.

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Per AF letter dtd 16 October 1974 signed William O. Cole

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INVESTIGATION OF VARIOUS FULL-SCALE PARACHUTES AT MACH NUMBER 3.0

David E. A. Reichenau
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FOREWORD

The work reported herein was done at the request of and for the Air Force Flight Dynamics Laboratory (AFFDL), Research and Technology Division (RTD), Air Force Systems Command (AFSC), under Program Element 62405364, Project 6065.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from August 11 to 13 and on September 30, 1965 under ARO Project No. PS0609, and the manuscript was submitted for publication on October 26, 1965.

This technical report has been reviewed and is approved.

Francis M. Williams Major, USAF AF Representative, PWT DCS/Test	Jean A. Jack Colonel, USAF DCS/Test

ABSTRACT

Several hyperflo and parasonic parachutes and one hemisflo parachute were tested in the 16-ft supersonic wind tunnel to obtain drag, inflation, and stability characteristics at a nominal Mach number of 3.0 and a nominal free-stream dynamic pressure of 120 psia. The effects of various types of roof mesh and material on the aerodynamic characteristics of the parachutes were obtained. These data show that the hyperflo parachutes had higher drag loads but less inflation and stability than the corresponding parasonic parachutes with the same combination of roof mesh and material. Differences in roof designs resulted in a drag variation of approximately 25 percent for both the hyperflo and parasonic series of 4-ft nominal diameter parachutes.

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NOMENCLATURE

A_e	Parachute exit area, sq ft
A_i	Parachute inlet area, sq ft
C_{D_O}	Parachute drag coefficient, $\frac{F_D}{q_\infty S_O}$
D_O	Parachute nominal diameter, ft
d	Model centerbody diameter, 1.47 ft
F_D	Parachute drag force, lb
M_∞	Free-stream Mach number
q_∞	Free-stream dynamic pressure, psfa
R_c	Parachute cap radius, ft
S_O	Parachute drag-producing surface, ft^2
X	Distance from aft end of centerbody to parachute inlet, ft

SECTION I
INTRODUCTION

A test was conducted in the 16-ft supersonic tunnel (Propulsion Wind Tunnel, Supersonic (16S)) of the Propulsion Wind Tunnel Facility (PWT) to determine the steady-state drag, inflation, and stability characteristics of parachutes in supersonic flow. It was also desired to establish the influence of the various roof meshes on parachute stability. The parachutes investigated during this test were of the hyperflo, parasonic, and hemisflo configurations. All of the parachutes were tested at a nominal Mach number of 3.0 and a free-stream dynamic pressure of 120 psfa.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16S is a closed-circuit, continuous flow wind tunnel currently capable of operating at Mach numbers from 1.65 to 3.20. The tunnel is capable of operating over a stagnation pressure range from 100 to 1600 psfa. The test section stagnation temperature can be controlled through the range from 100 to 650°F. The wind tunnel specific humidity is controlled by removing tunnel air and supplying makeup air from an atmospheric dryer. A more complete description of the facility and its operating characteristics is contained in the Test Facilities Handbook.[1]

2.2 TEST ARTICLE

2.2.1 Model Centerbody and Deployment System

The parachutes tested during this investigation were deployed from a strut-mounted centerbody. Dimensions of the centerbody are presented in Fig. 1, and the location of the centerbody in the wind tunnel is shown in Fig. 2. The wind tunnel installation of the centerbody is shown in Fig. 3.

---

[1]Test Facilities Handbook (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.

The parachutes were packed in the aft end of the centerbody on a spring-loaded plate and were held against the plate by retaining straps. The retaining straps were released by a squib-fired release-pin mechanism. A three-quarter rear view of a parachute packed in the aft end of the centerbody is shown in Fig. 4. The parachute riser line was affixed to a load cell inside the centerbody by means of a swivel which was used to prevent twisting of the parachute suspension lines. A shear pin, designed to protect the load cell, was used to connect the parachute riser line to the swivel.

2.2.2 Parachutes

The parachutes tested were of three general types: hyperflo, parasonic, and hemisflo. Specific construction details and photographs of the parachutes are shown in Figs. 5 through 13.

The six hyperflo (truncated-cone shape) parachute configurations had a nominal diameter of 4 ft. Five of the hyperflo parachutes, Configurations 1 through 5 shown in Fig. 6, had differently constructed mesh roofs made of nylon or Perlon® thread. The porosity of each parachute, Configurations 1 through 5, was kept approximately the same by using porosity bands built into the roofs of the parachute canopies. Configuration 15, also shown in Fig. 6, had a mesh roof constructed of 1/4-in.-wide cotton webbing. The skirt, porosity band, suspension lines, and riser lines of the hyperflo parachutes were of nylon construction. The parachute porosity, as used in this report, is defined as the ratio of the open area in the drag-producing surface to the total area of the drag-producing surface.

The details of the parasonic parachutes, Configurations 6 through 12 and Configuration 14, are shown in Figs. 8, 9, and 10. The parasonic parachutes were constructed in the shape assumed by a hyperflo parachute when it is in a fully inflated condition. The 4-ft nominal diameter parasonic parachutes, Configurations 6 through 10, shown in Fig. 8, were constructed of identical roof mesh and nylon material as a corresponding hyperflo configuration (as shown in Table I). The porosity of each of these five configurations was kept essentially the same by varying the porosity band in the roof. The porosities of the parasonic parachutes were slightly lower than those of the corresponding hyperflo parachutes. Configurations 11 and 12 were identical parasonic parachutes with a nominal diameter of 5.5 ft. These two parasonic parachutes were of nylon construction. The specific construction details and a photograph are shown in Figs. 9 and 11, respectively. Configuration 14, shown in Fig. 10, was constructed of the identical cotton webbing and nylon material that was used for hyperflo Configuration 15.

Configuration 13, a hemisflo parachute, had a roof and skirt constructed of 0.75-in.-wide nylon ribbons and 14.5-in.-wide solid nylon mesh, respectively. The riser and suspension lines were also nylon. The hemisflo parachute had a nominal diameter of 6 ft and a porosity of 8 percent. Details of Configuration 13 are shown in Fig. 12; a photograph of this parachute is shown in Fig. 13.

2.3 INSTRUMENTATION

A 5000-lb-capacity, double-element load cell was used to measure the drag load of the parachutes. A direct-writing oscillograph was used to monitor the parachute drag load during testing. Four motion-picture cameras and two television cameras, installed in the test section walls, were used to document and monitor these tests.

SECTION III
PROCEDURE

A parachute was packed into the aft end of the strut-mounted centerbody before initiation of the wind tunnel test operations. Once test conditions were established, the parachute was ejected from the centerbody into the airstream. Motion pictures and dynamic drag data were obtained during and after each deployment. Upon the completion of the parachute deployment sequence, a steady-state load drag was calculated by averaging the analog output signal from the strain-gage load cell over a 1-sec interval.

All of the parachute configurations were deployed at a nominal Mach number and free-stream dynamic pressure of 3.0 and 120 psfa, respectively. The centerbody was maintained at zero angle of attack and yaw for the entire test. A complete summary of test conditions is presented in Table II.

SECTION IV
RESULTS AND DISCUSSION

Fifteen parachute deployments were made at a Mach number of 3.0 and a free-stream dynamic pressure of 120 psfa. Data were obtained at Mach number 3.0 for all of these parachutes except Configuration 3, which failed on deployment. Additional data were obtained at Mach numbers of 2.8 and 2.6 for Configuration 14. All other parachutes failed before a new

Mach number condition could be established. A complete summary of the test results is given in Table II.

4.1 DEPLOYMENT LOADS

Deployment of parachutes generally creates two forces known as the "snatch force" and the "opening shock force." For wind tunnel testing of parachutes, the snatch force is defined as that force imposed on the centerbody by the deceleration of the mass of the parachute from its velocity at line extension to zero velocity relative to the centerbody. The snatch force is followed closely by the opening shock force, which is defined as that force imposed on the centerbody by the sudden inflation of the parachute at full line extension.

For the fifteen parachute configurations investigated, the snatch and opening shock forces were found to vary considerably during each deployment, since they are a function of the parachute packing procedure. The deployment-time histories of each of the parachute configurations are shown in Fig. 14. As shown in Figs. 14b and d, Configurations 2 and 4 had extremely high snatch forces. Analysis of motion pictures of these two configurations shows that the parachutes separated from the deployment can before the parachute reached full line extension, thus superimposing the opening shock force on the snatch force. Several of the parachute configurations tested later were repacked and reinforced with "break thread" to prevent premature opening of the parachutes. The snatch and opening shock forces for all the parachutes varied between 250 and 1200 lb, and between 500 and 1800 lb, respectively.

4.2 STEADY-STATE LOADS

The drag coefficient for each of the parachute configurations is presented in Table II. The drag coefficients for the parachutes investigated ranged from 0.21 to 0.30.

The 4-ft hyperflo parachutes (Configurations 1 through 5 and 15) had a higher drag coefficient than the corresponding 4-ft parasonic parachute with identical roof mesh and material (Configurations 6 through 10 and 14). It is believed that the higher drag coefficients obtained with the hyperflo parachutes were a result of the particular parachute design rather than the small variations in porosity and inlet-to-exit area ratios between the corresponding hyperflo and parasonic parachute configurations. In general, a hyperflo parachute has a slightly larger inflated diameter than a parasonic parachute of the same nominal diameter. The drag coefficient was also affected by varying the mesh roof design in the 4-ft parachute configurations. Differences in the roof designs resulted in a drag coefficient

variation of approximately 25 percent for the hyperflo and parasonic series of 4-ft parachutes. Configurations 1 and 6 had the highest drag coefficients for the hyperflo and parasonic parachutes, respectively. The difference in the drag coefficients for the two identical 5.5-ft nominal diameter parasonic parachutes (Configurations 11 and 12) was caused by underinflation of Configuration 12, thus producing a smaller drag load. Configuration 13, a 6-ft nominal diameter hemisflo parachute, had the largest drag coefficient of the parachutes tested, a value of 0.304.

4.3 INFLATION AND STABILITY CHARACTERISTICS

Photographic coverage obtained by motion-picture cameras permitted the determination of the parachute inflation and stability characteristics. Analysis of the motion pictures indicated that the 4-ft parasonic parachute configurations exhibited full canopy inflation during each deployment. However, the hyperflo parachute configurations, with the exception of Configuration 1, exhibited less inflation stability than did the parasonic parachutes because of squidding and skirt flutter. Configurations 12 and 13, the 5.5-ft parasonic and 6-ft hemisflo parachutes, respectively, also exhibited full canopy inflation. For no apparent reason, Configuration 11, identical in construction to Configuration 12, exhibited underinflation.

The parachute stability characteristics as discussed in this report pertain to the motion of the canopy in a plane perpendicular to the centerline of the centerbody. The motion was defined in terms of maximum oscillation angle and oscillation frequency about the riser line to centerbody attachment point and was evaluated from motion pictures. A tabulation of the stability characteristics for the parachute configurations is presented in Table II. The oscillation angle of the 4-ft hyperflo parachutes varied between ±6.5 and ±13 deg, whereas the oscillation angle of the 4-ft parasonic parachutes varied between ±3.5 and ±12 deg. The oscillation frequency of the 4-ft hyperflo and parasonic parachutes varied between 4.0 and 4.5 cps and 2.0 and 4.0 cps, respectively. In each case, for a given parachute roof mesh and material, the parasonic parachute configuration had a lower oscillation angle and frequency than did the hyperflo parachute configuration. For Configuration 14, where data were obtained at Mach numbers of 3.0, 2.8, and 2.6, the oscillation angle and frequency decreased with decreasing Mach number.

SECTION V
CONCLUDING REMARKS

Tests were conducted to investigate the drag, inflation, and stability characteristics of several parachutes with various roof mesh and material combinations in supersonic flow. The following observations are a result of these tests:

1. The hyperflo parachute configurations had a higher drag coefficient than the corresponding parasonic parachute configuration with identical roof mesh and material.
2. Differences in roof designs resulted in a drag coefficient variation of approximately 25 percent for both the hyperflo and parasonic series of 4-ft parachutes.
3. The inflation and stability characteristics of the parasonic parachute configuration were better than those of the corresponding hyperflo parachute configuration with identical roof mesh and material.

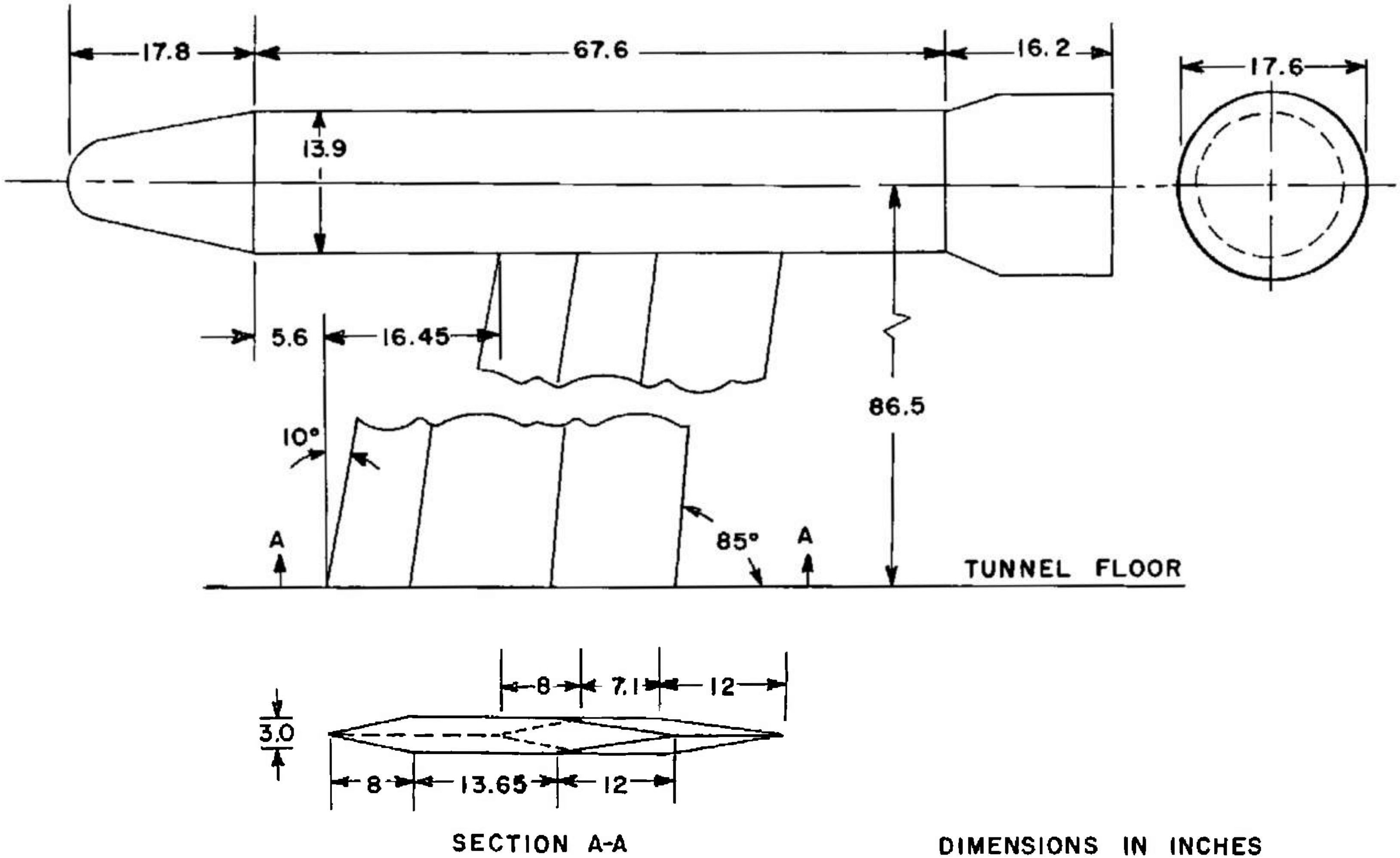


Fig. 1 Model Centerbody Dimensions

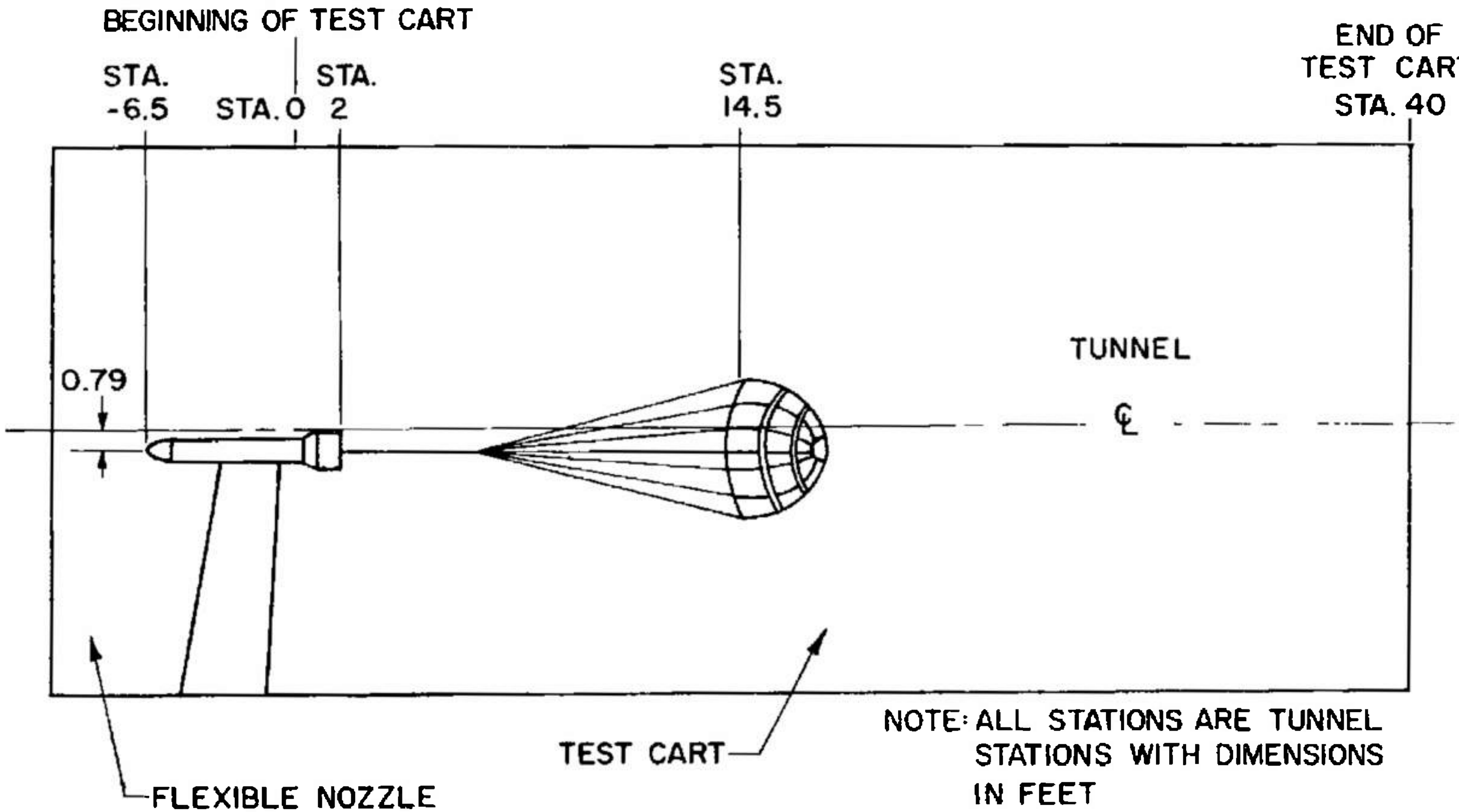


Fig. 2 Location of Model in Test Section

Fig. 3 Installation of Full-Scale Model Centerbody in Test Section

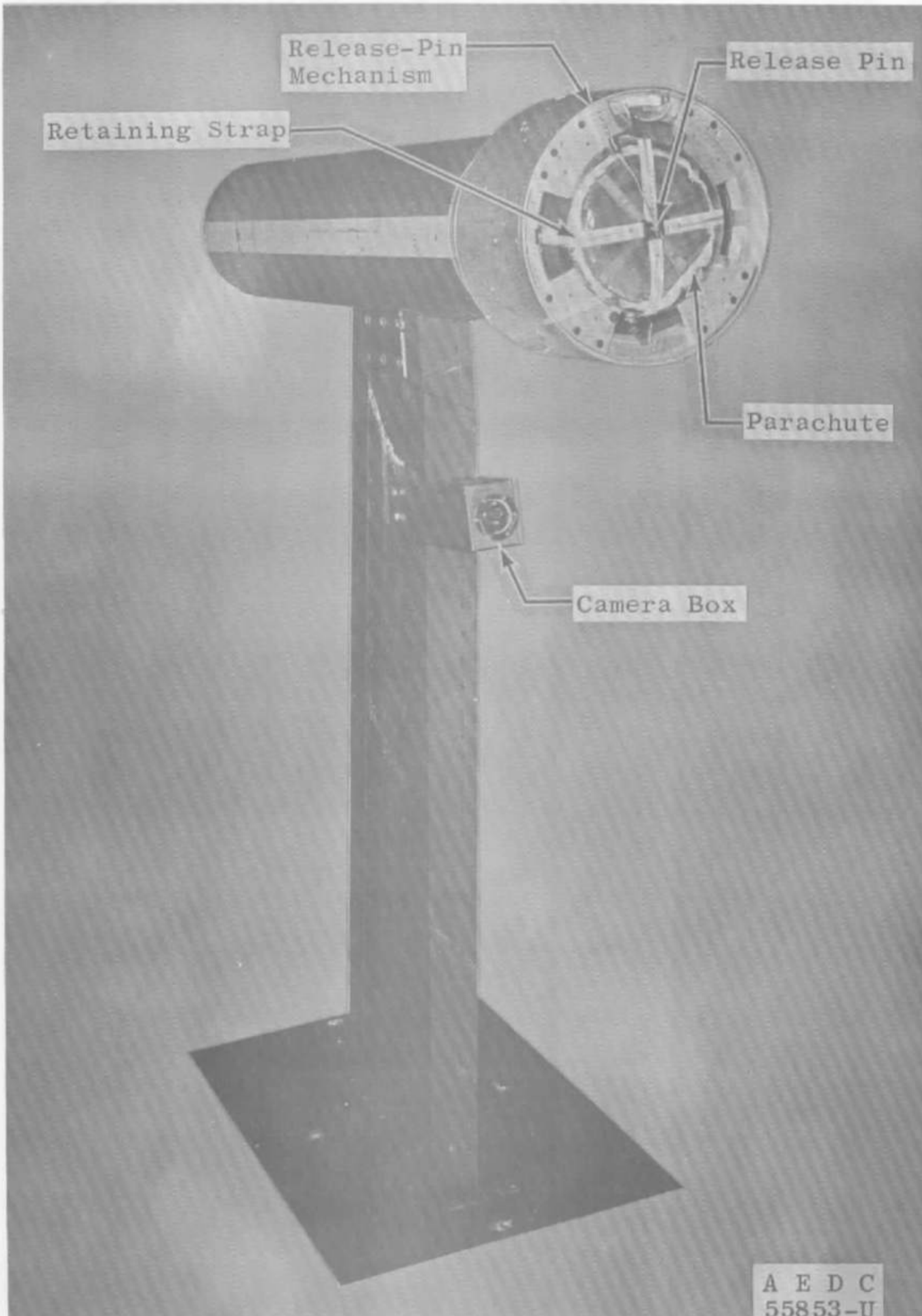
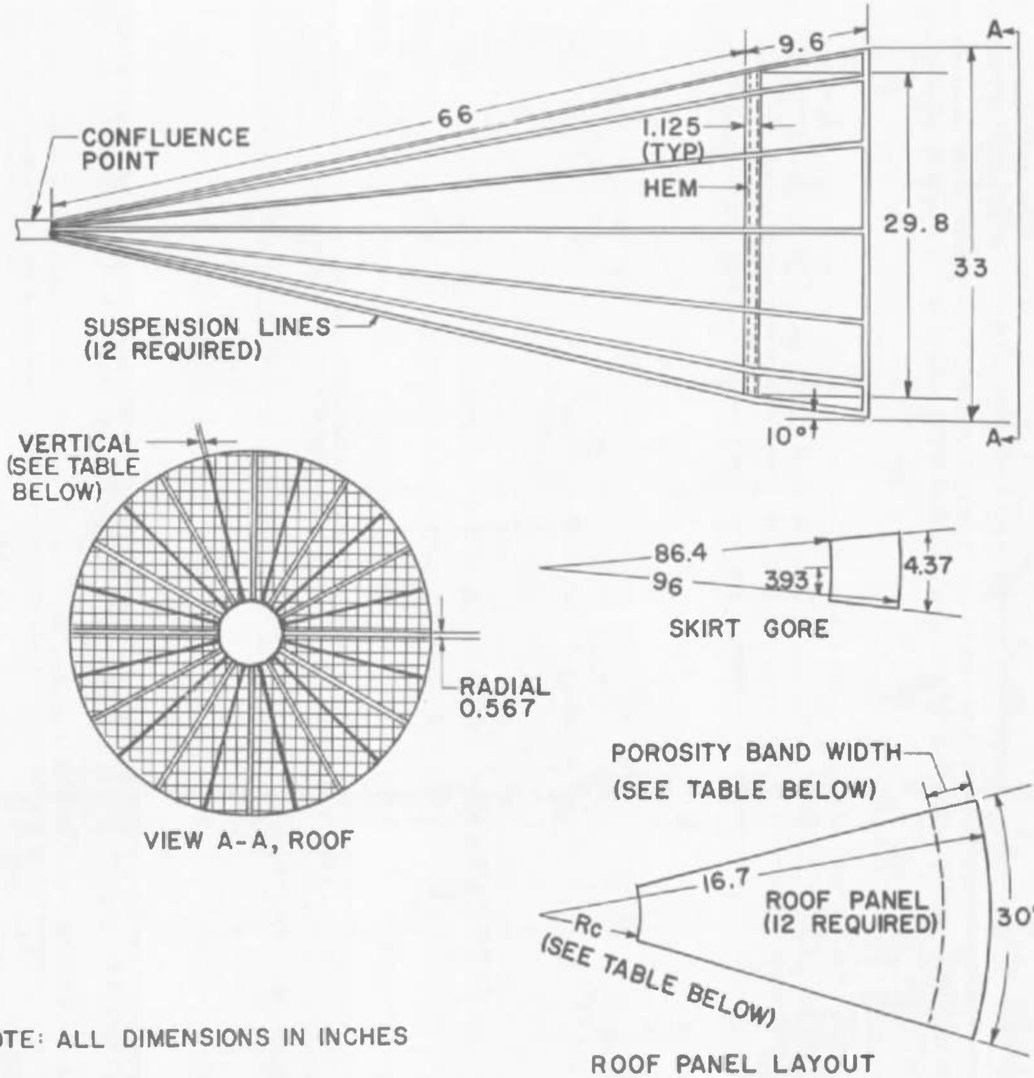


Fig. 4 Three-Quarter Rear View of Model Centerbody



PARACHUTE CONFIGURATION	CAP RADIUS Rc	POROSITY BANDWIDTH	VERTICAL WIDTH
1	3.25	NONE	0.375
2	10.30	3.3	"
3	3.20	NONE	"
4	10.00	3.2	"
5	10.75	4.1	"
15	3.00	NONE	0.567

Fig. 5 Hyperflo Parachute Details, Configurations 1 through 5 and Configuration 15

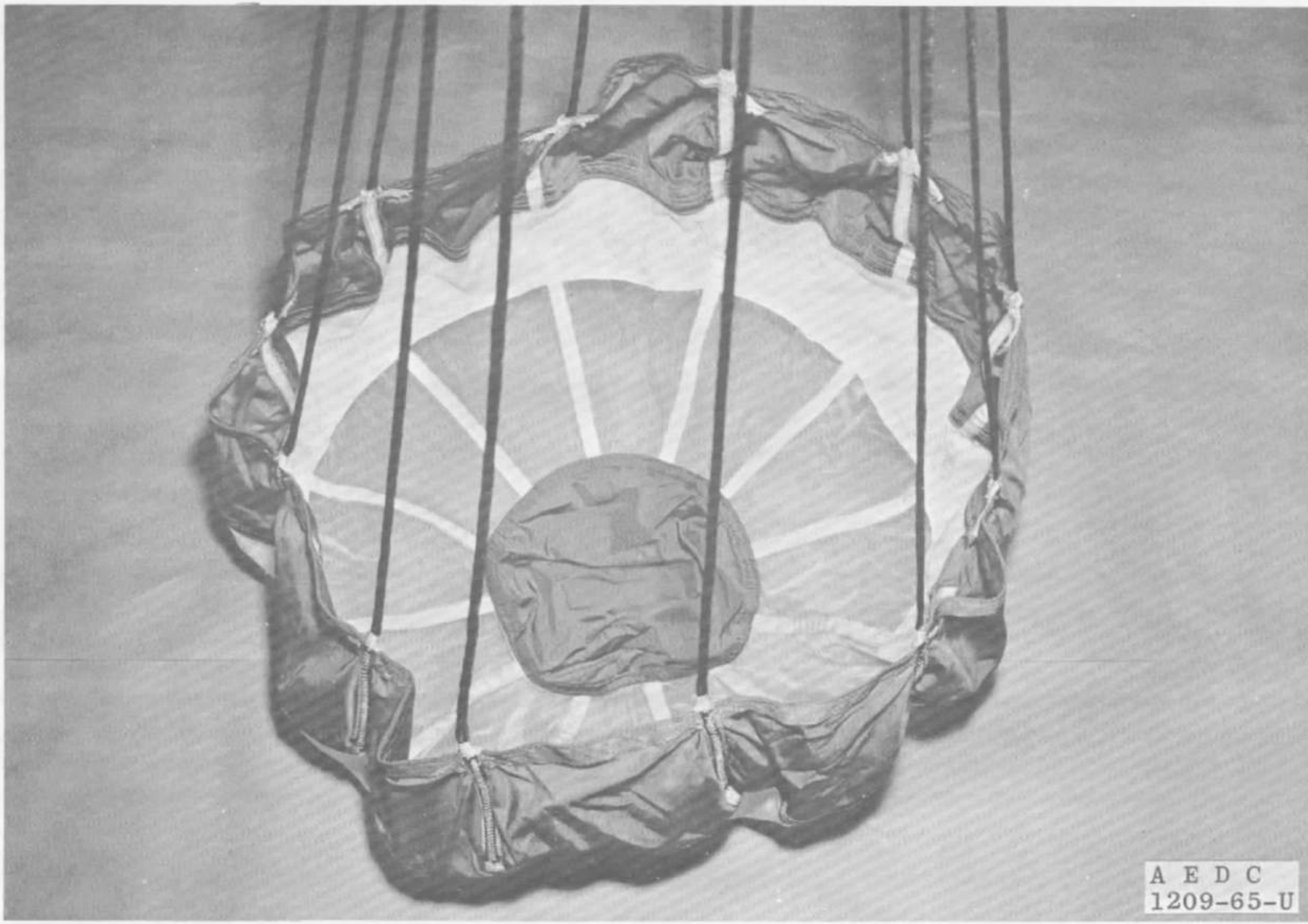


Fig. 6 Hyperflo Parachute

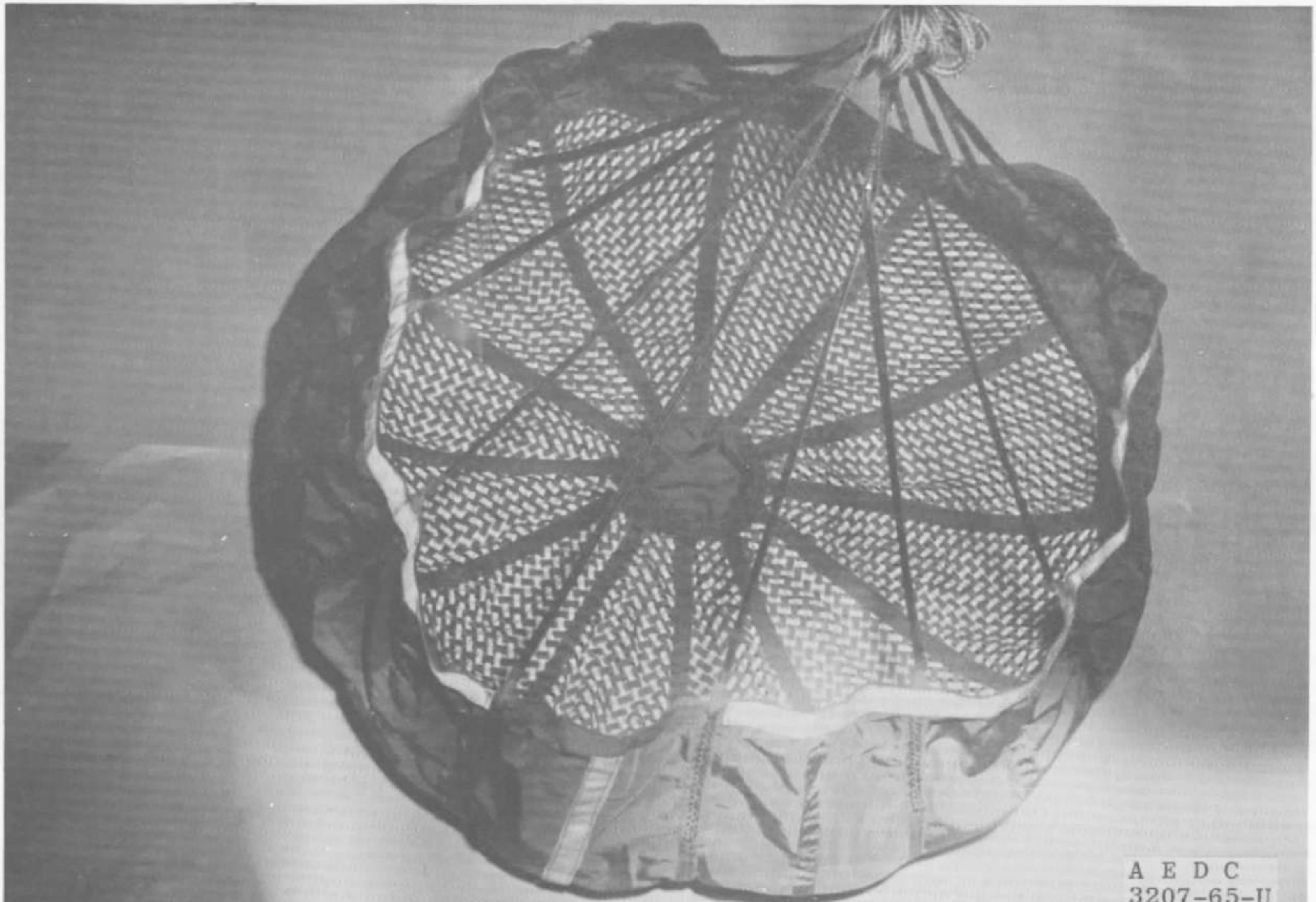
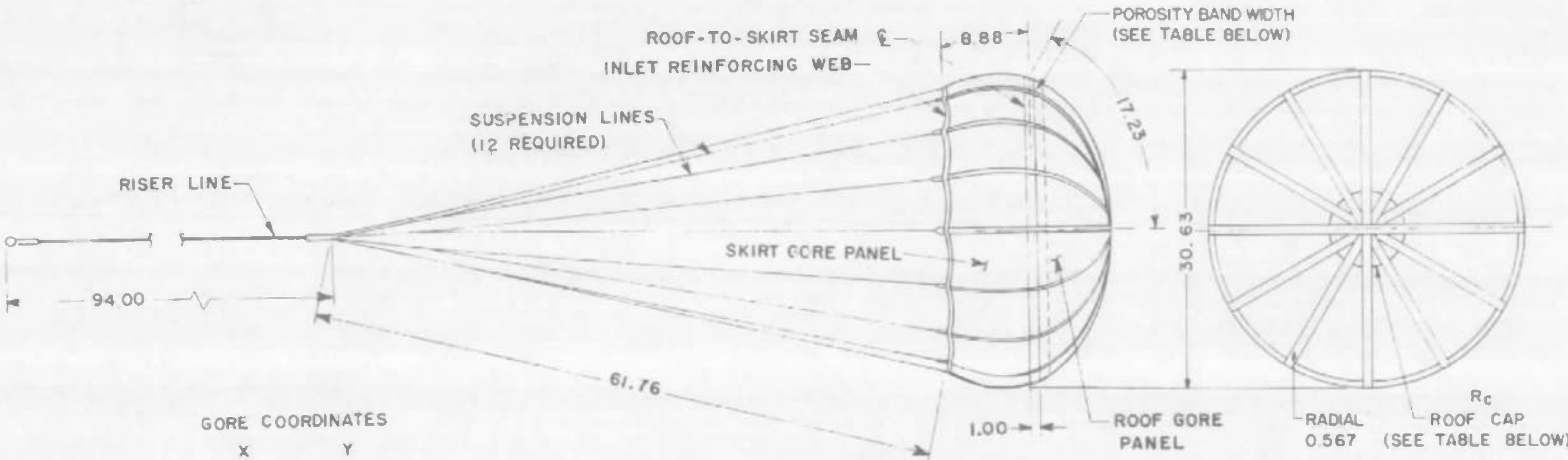
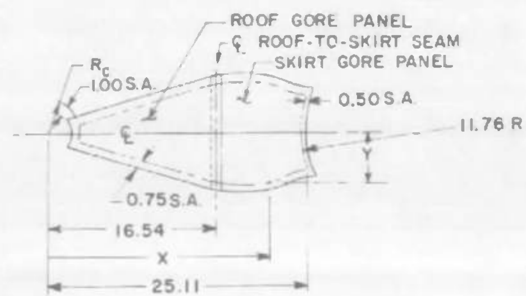


Fig. 7 Configuration 15, with Quarter-Inch Webbing Mesh Roof



GORE COORDINATES

X	Y
0	0
3.06	0.84
6.12	1.70
9.19	2.60
12.25	3.52
15.32	4.36
16.54	4.59
18.38	4.84
20.03	4.91
21.44	4.78
22.16	4.56
22.94	4.24
23.46	3.97
24.00	3.71
24.53	3.58
25.11	3.57

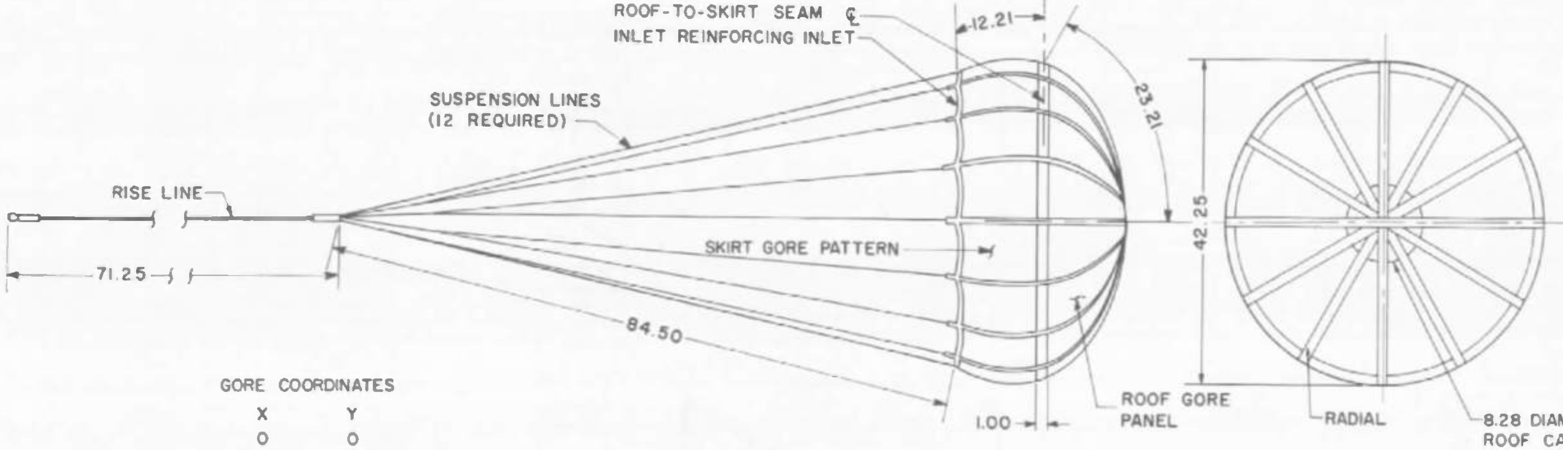


CANOPY GORE PATTERN
(12 REQUIRED)

PARACHUTE CONFIGURATION	CAP RADIUS Rc	POROSITY BAND WIDTH
6	1.5	NONE
7	5.0	3
8	5.0	4
9	5.0	0.75
10	5.0	3

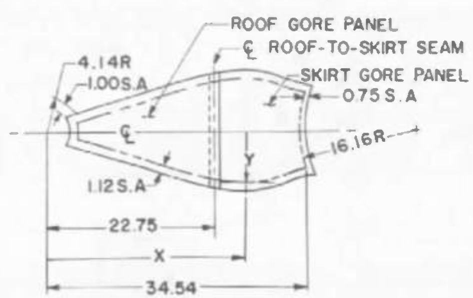
NOTES: ALL DIMENSIONS IN INCHES
S.A. = SEAM ALLOWANCE

Fig. 8 Parasonic Parachute Details, Configurations 6 through 10



GORE COORDINATES

X	Y
0	0
1.05	0.28
2.12	0.59
4.21	1.16
6.32	1.75
8.43	2.34
10.52	2.95
12.62	3.58
14.76	4.21
16.85	4.84
18.95	5.43
21.30	6.00
22.75	6.31
23.16	6.38
25.26	6.65
27.56	6.76
29.50	6.64
30.45	6.27
31.55	5.83
32.30	5.46
33.00	5.10
33.70	4.92
34.54	4.90

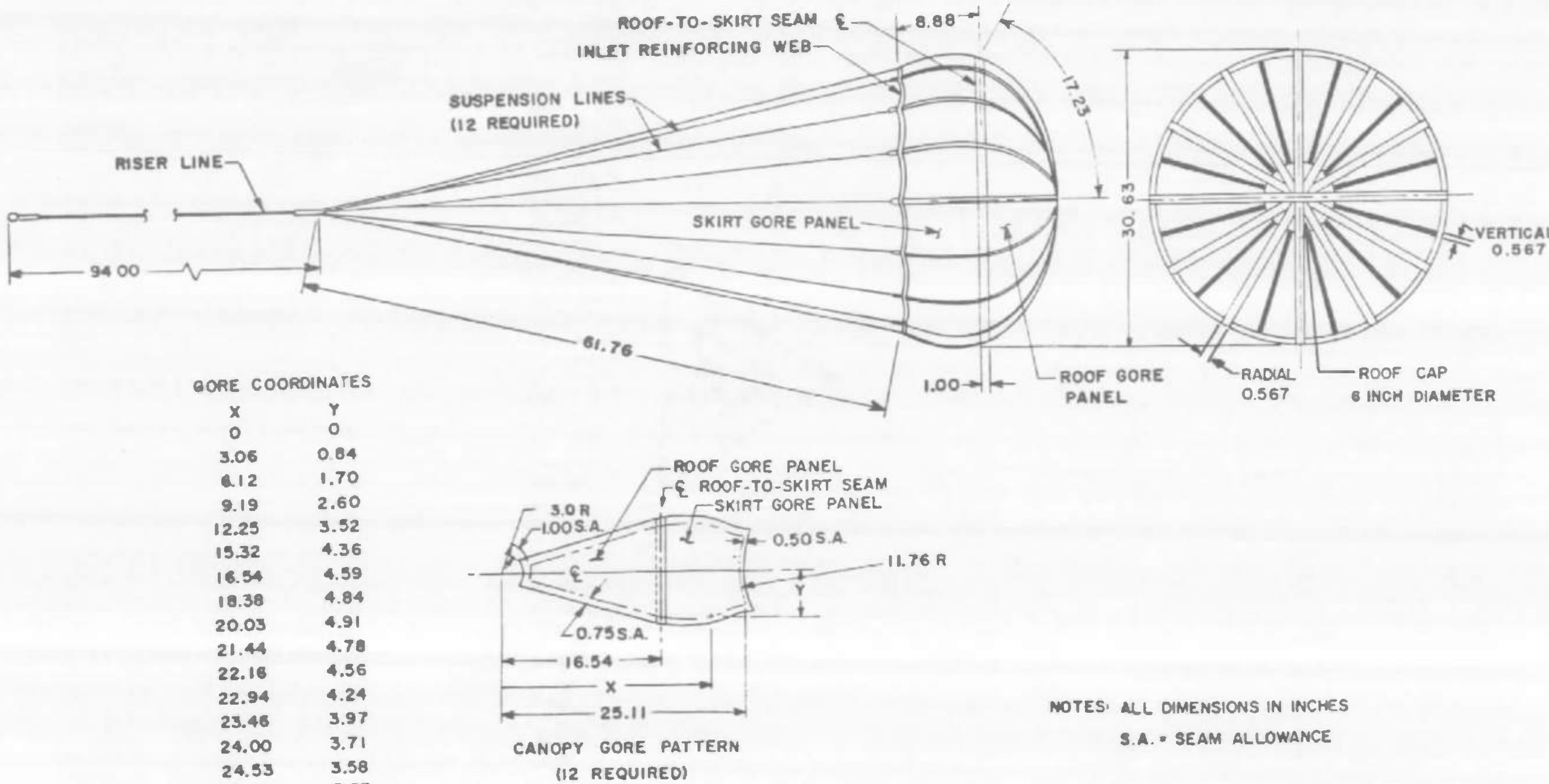


CANOPY GORE PATTERN
(12 REQUIRED)

NOTES: ALL DIMENSIONS IN INCHES

S.A = SEAM ALLOWANCE

Fig. 9 Parasonic Parachute Details, Configurations 11 and 12



GORE COORDINATES

X	Y
0	0
3.06	0.84
6.12	1.70
9.19	2.60
12.25	3.52
15.32	4.36
16.54	4.59
18.38	4.84
20.03	4.91
21.44	4.78
22.16	4.56
22.94	4.24
23.46	3.97
24.00	3.71
24.53	3.58
25.11	3.57

Fig. 10 Parasonic Parachute Details, Configuration 14

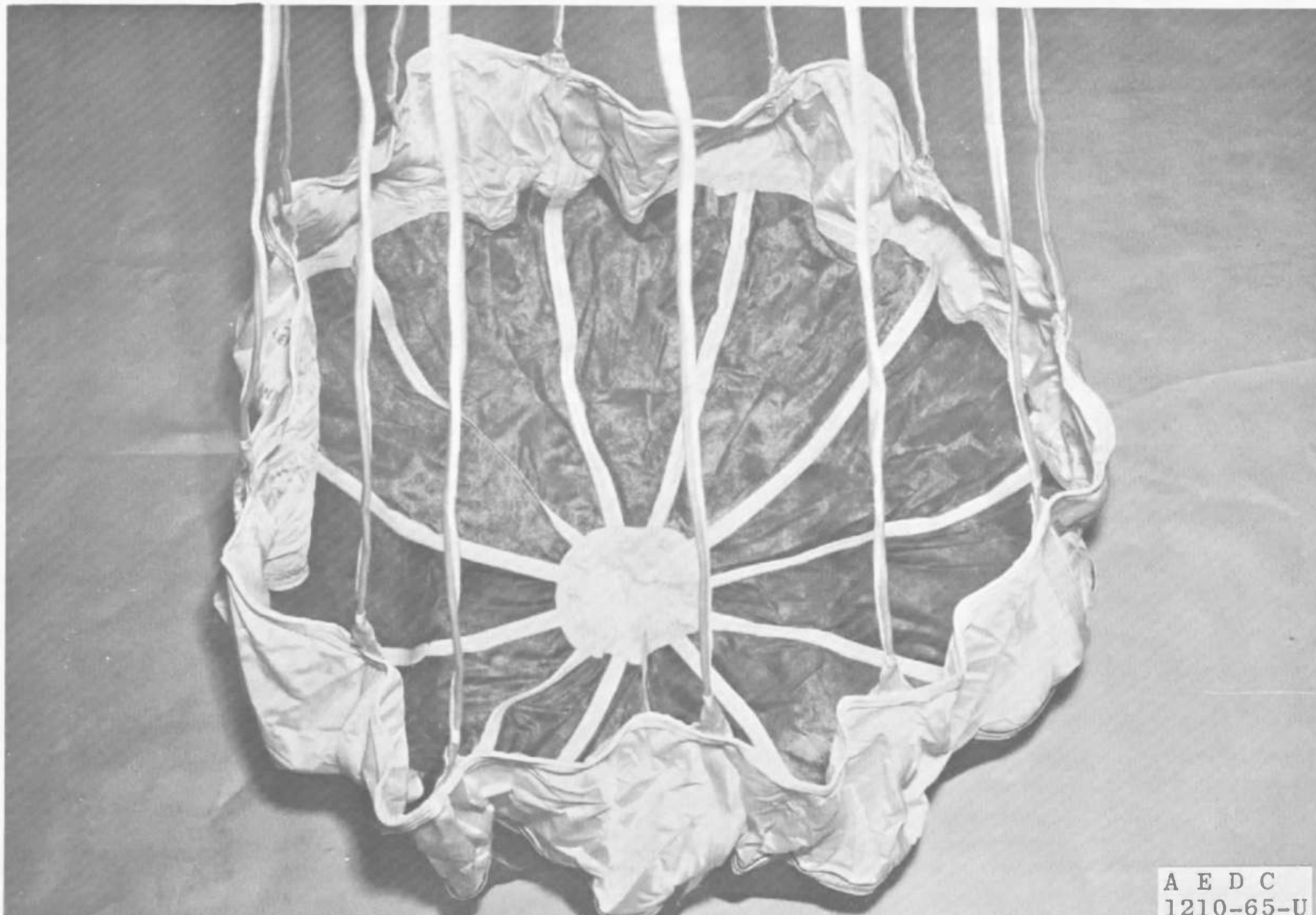
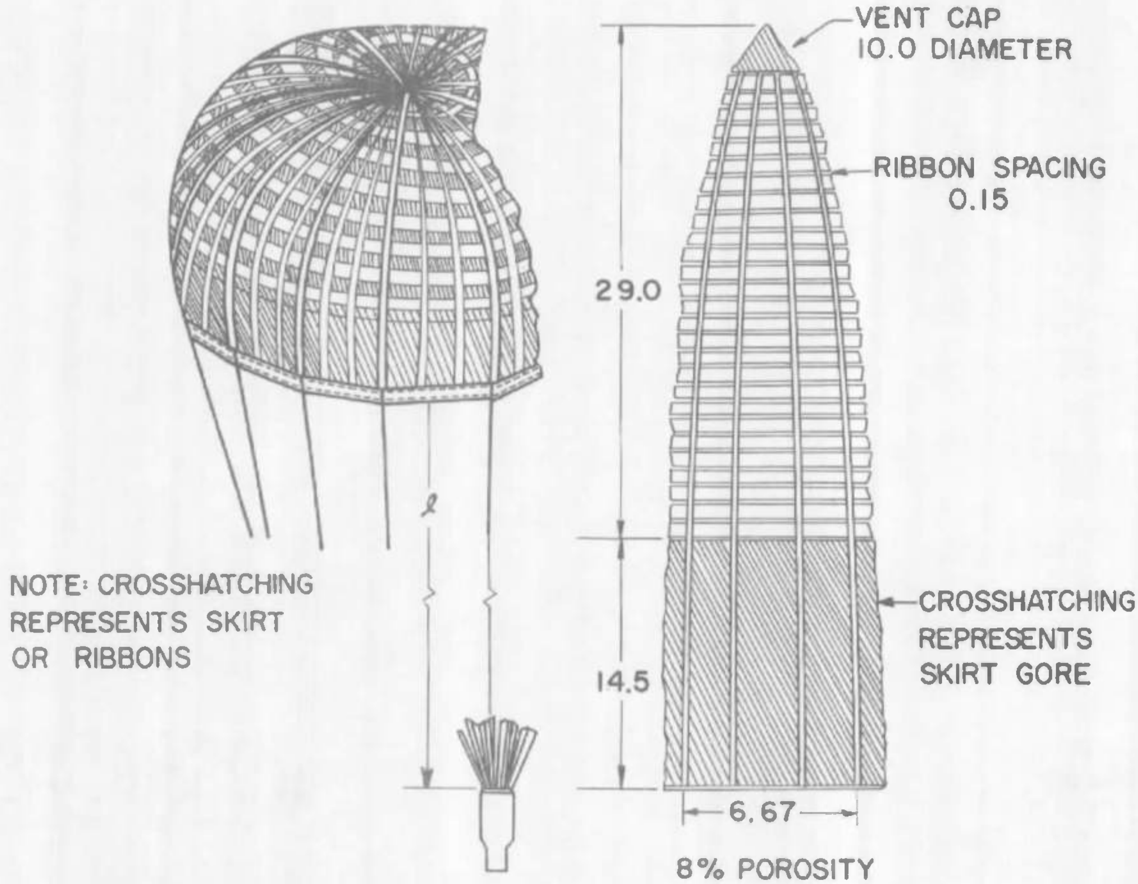


Fig. 11 Parasonic Parachute



HEMISFLO RIBBON
RIBBON WIDTH, 0.75 INCH
20 GORES
72 IN. NOMINAL DIAMETER
SUSPENSION LINE LENGTH, ℓ = 144 INCHES
SUSPENSION LINE WIDTH, 0.563 INCH

NOTE: ALL DIMENSIONS IN INCHES

Fig. 12 Hemisflo Parachute Details, Configuration 13

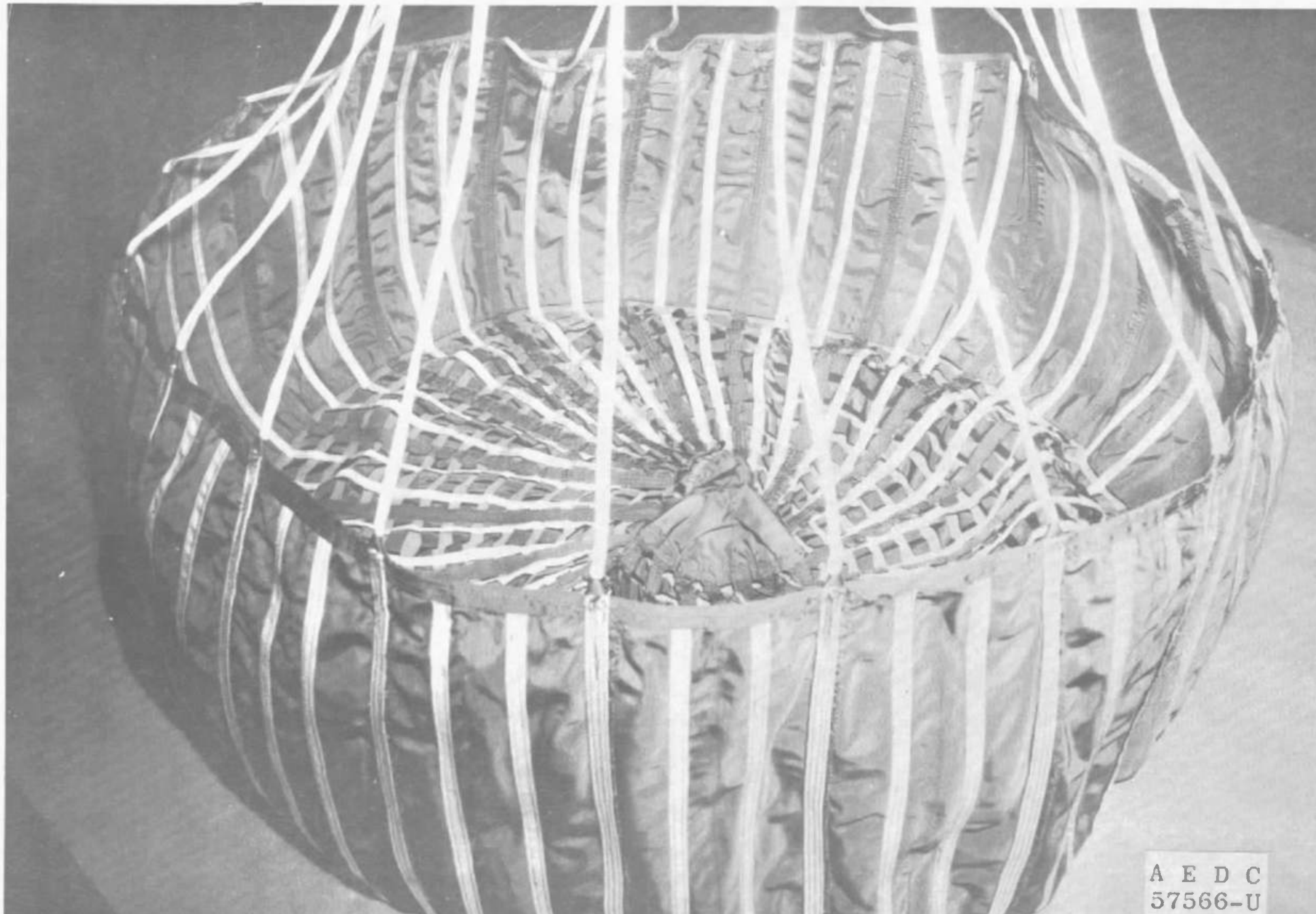
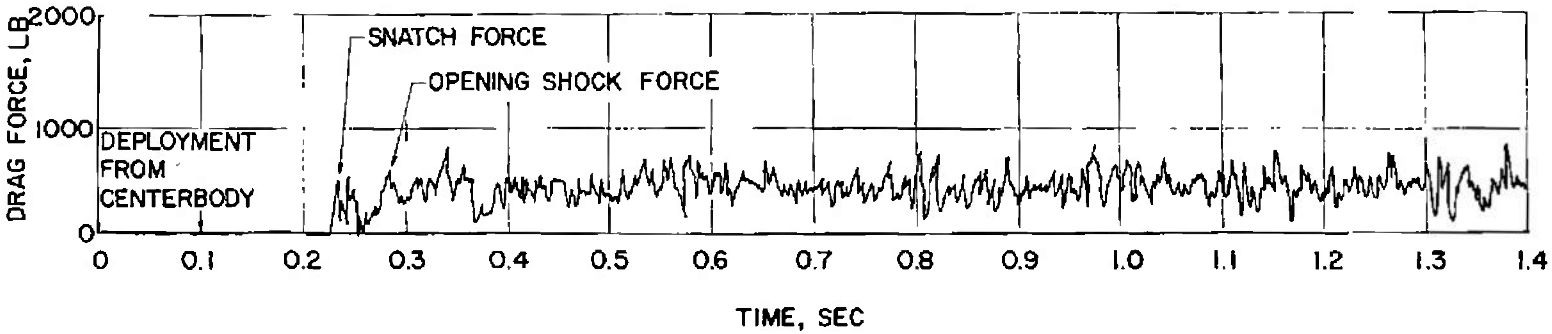
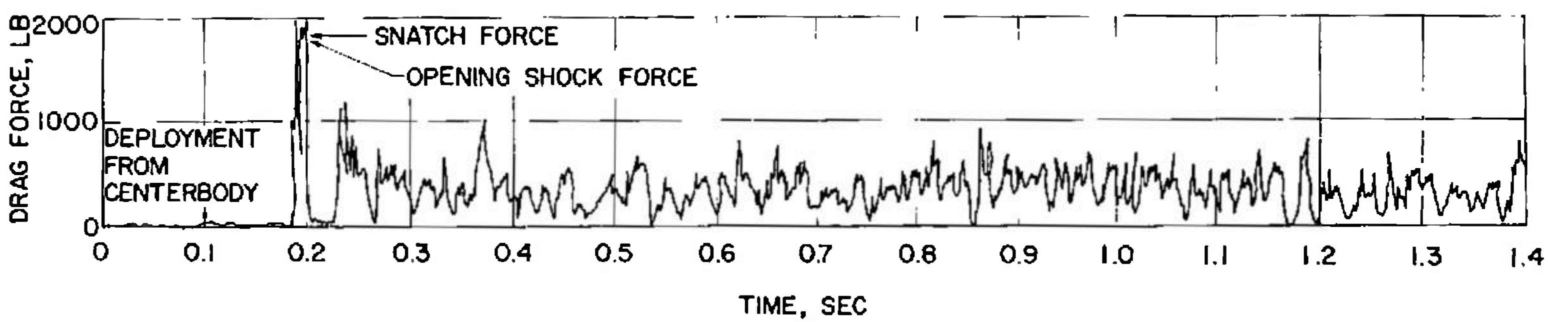


Fig. 13 Hemisflo Parachute

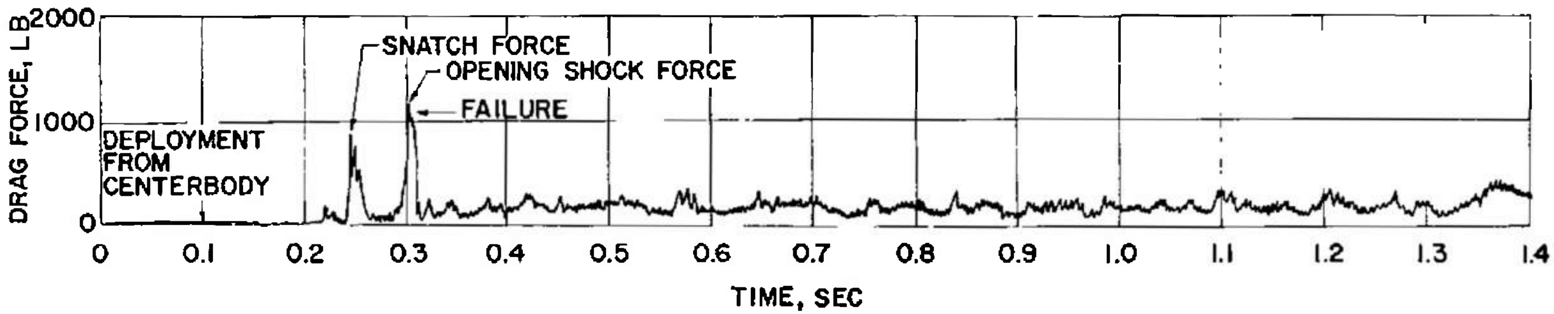


a. Configuration 1

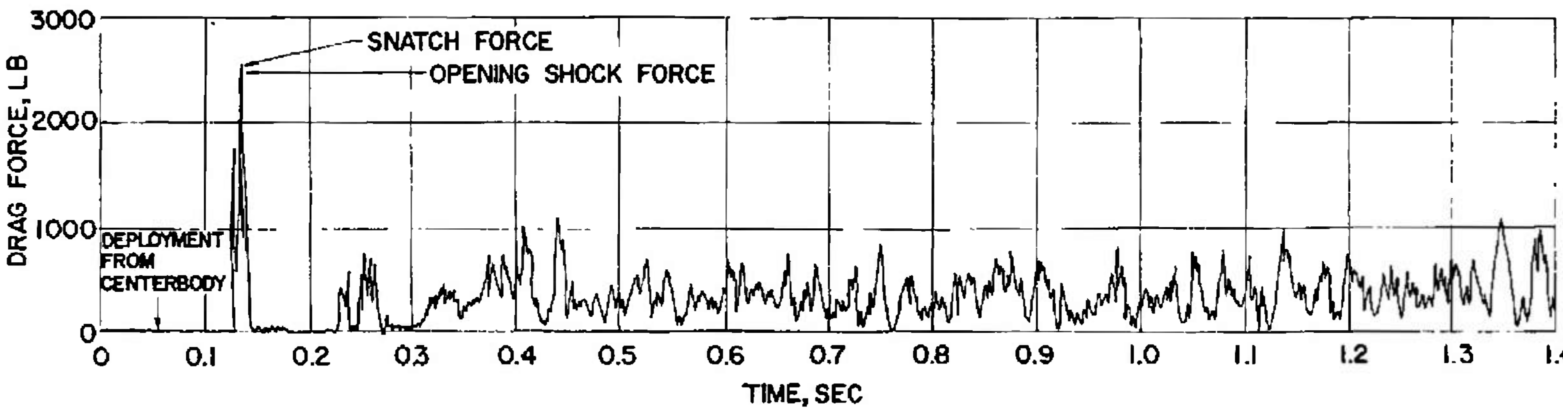


b. Configuration 2

Fig. 14 Parachute Deployment Characteristics

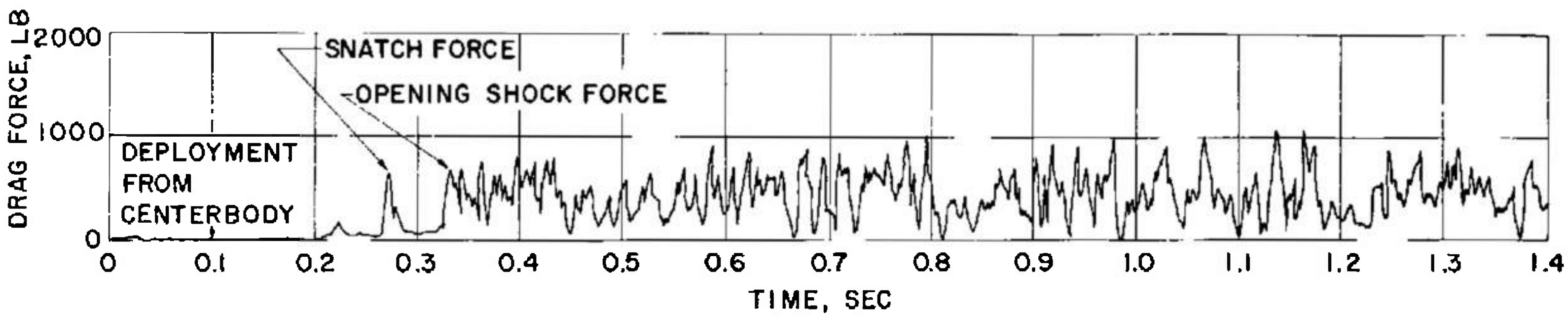


c. Configuration 3

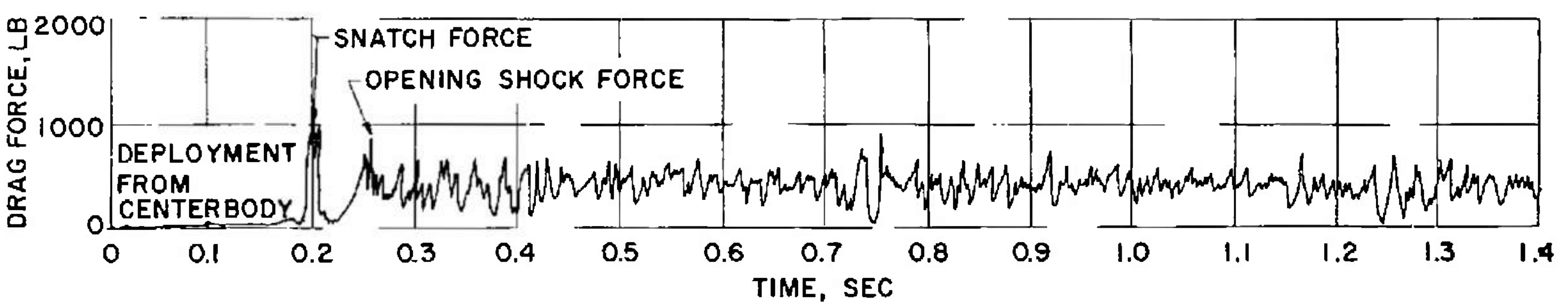


d. Configuration 4

Fig. 14 Continued

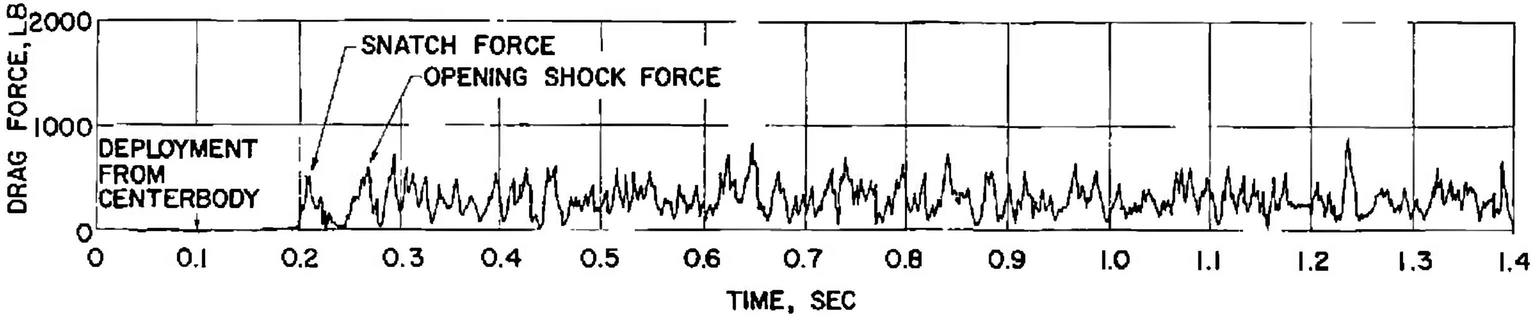


e. Configuration 5

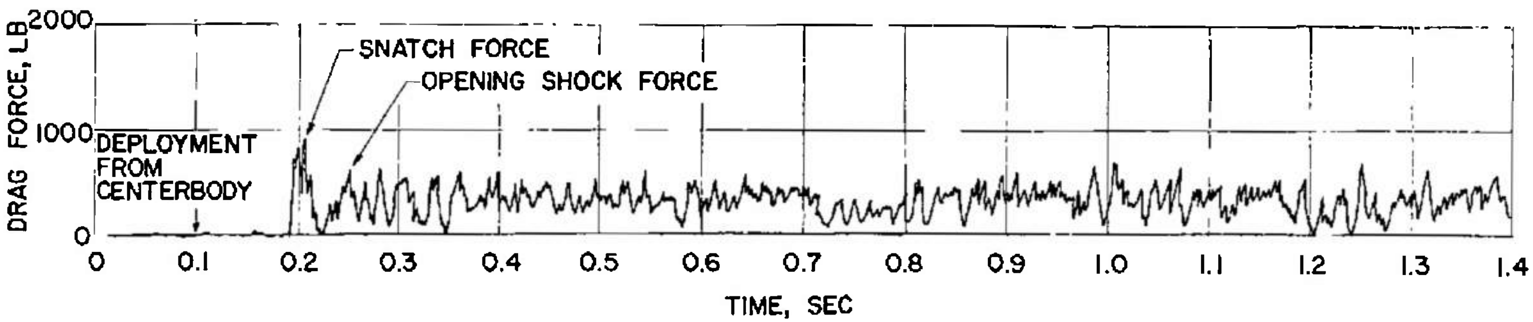


f. Configuration 6

Fig. 14 Continued

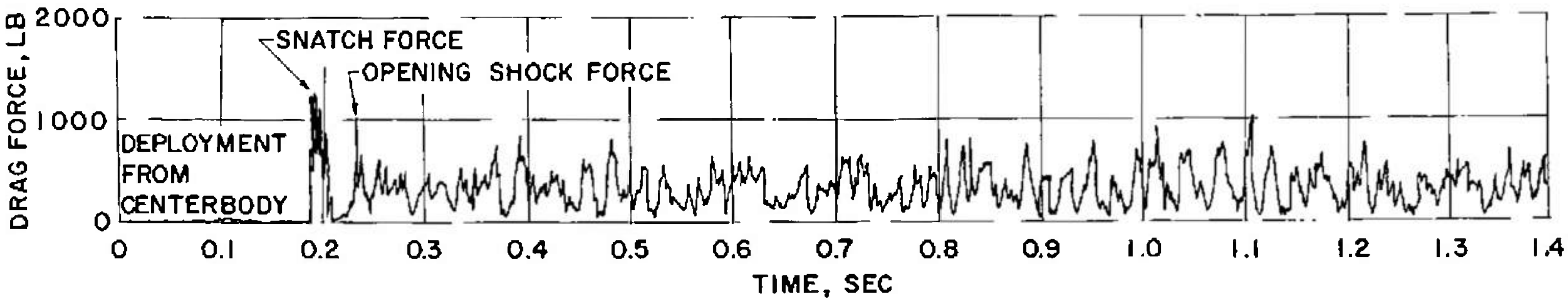


g. Configuration 7

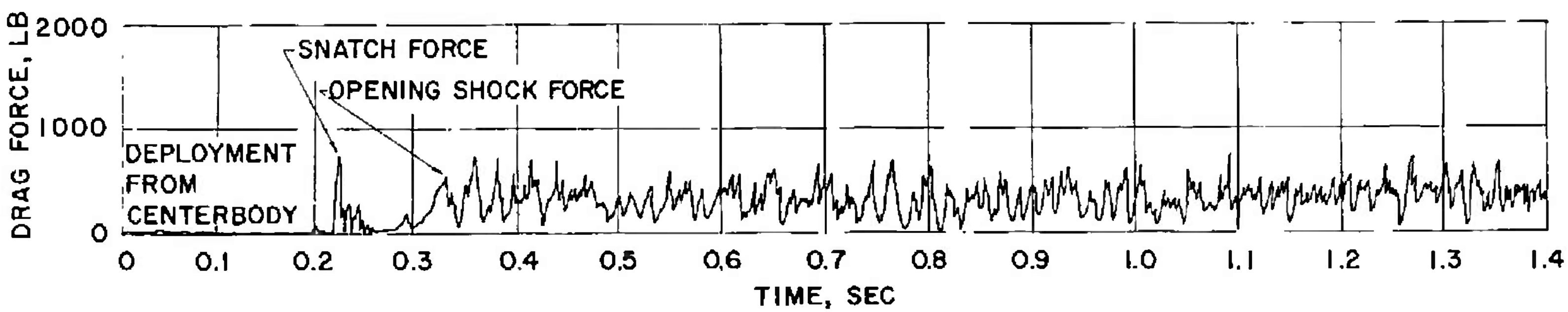


h. Configuration 8

Fig. 14 Continued

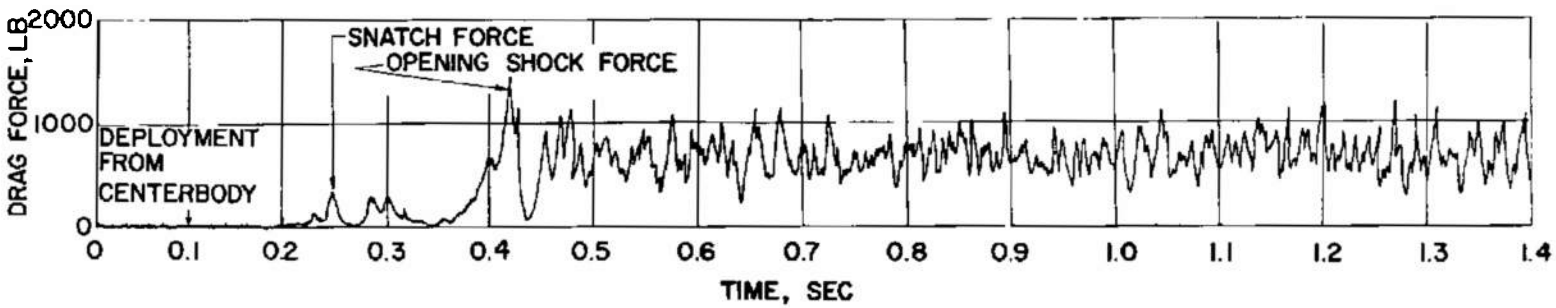


i. Configuration 9

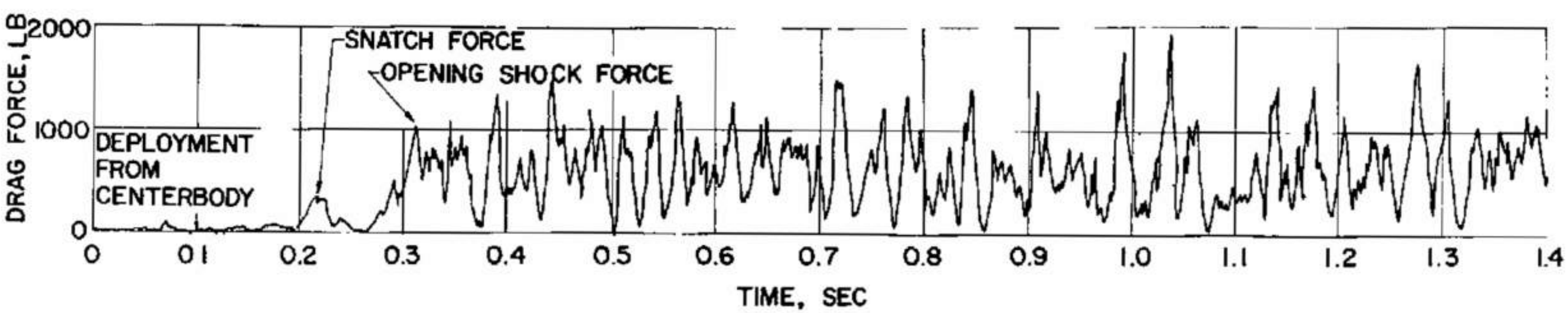


j. Configuration 10

Fig. 14 Continued

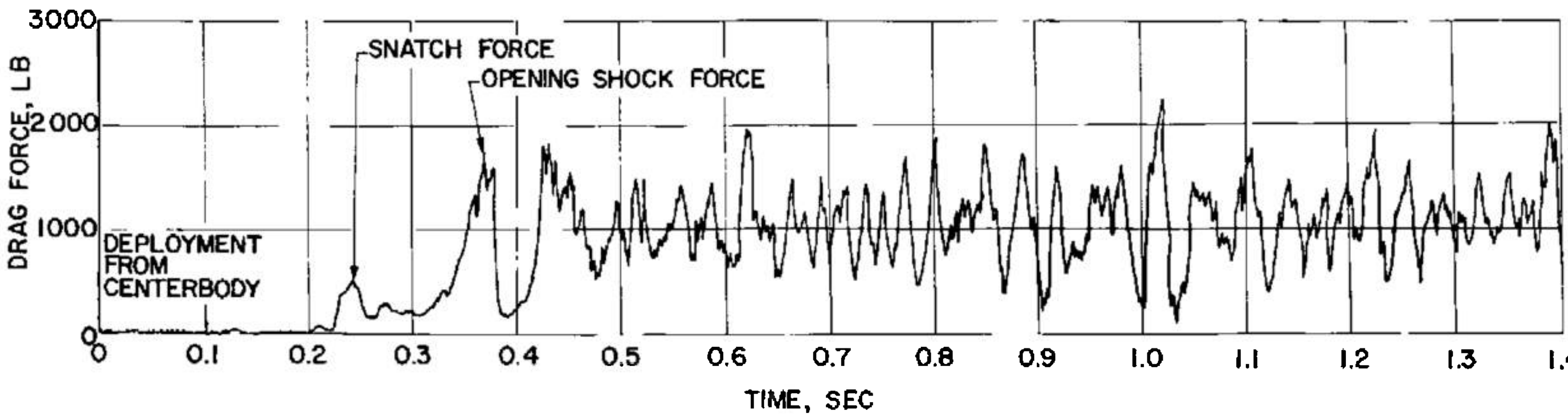


k. Configuration 11



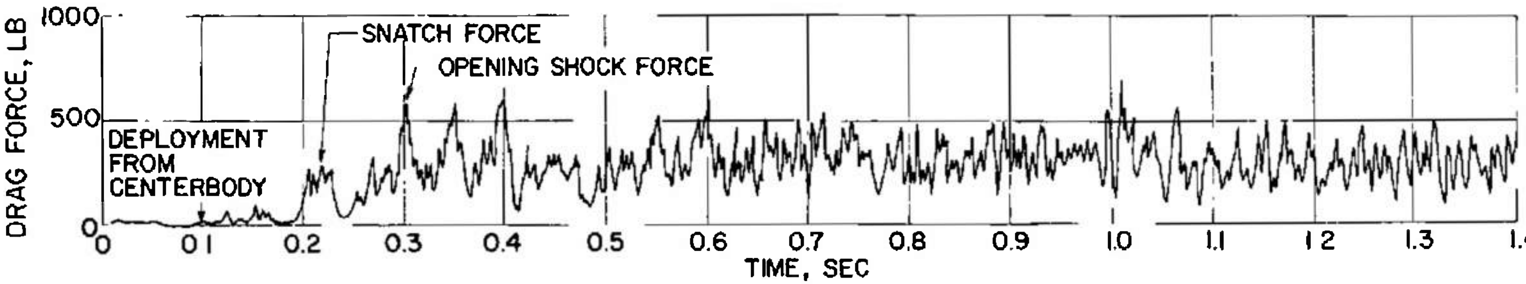
l. Configuration 12

Fig. 14 Continued

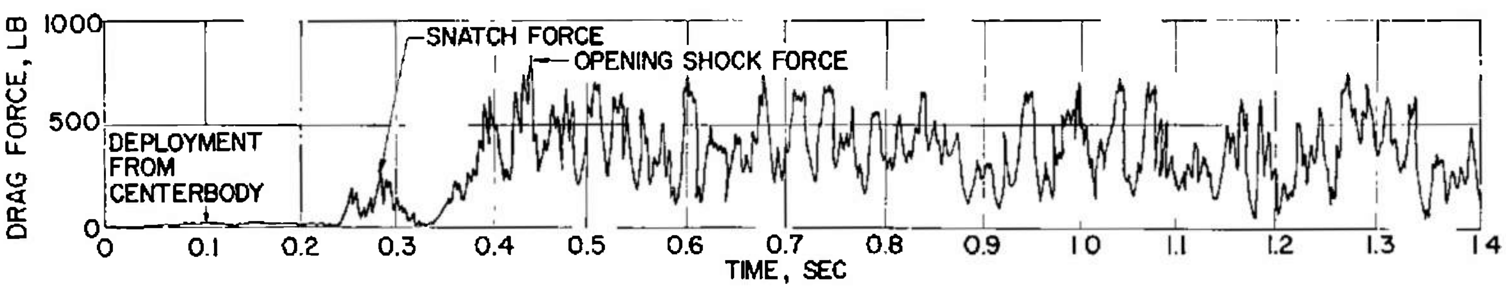


m. Configuration 13

Fig. 14 Continued



n. Configuration 14



o. Configuration 15

Fig. 14 Concluded

TABLE I
SUMMARY OF PARACHUTE DETAILS

Parachute Config-uration	Type	Parachute Nominal Diameter, ft	Parachute Porosity, percent	Area Ratio, A_i/A_e	Strength of Roof Material, lb/in. of width	Number of Threads Per Lineal Inch in Parachute Roof Material	Type of Material
1	Hyperflo	4.00	8.23	4.75	25	280 x 280	Nylon skirt, Perlon mesh roof
2	Hyperflo	4.00	10.50	4.50	49	230 x 230	Nylon skirt, Perlon mesh roof
3	Hyperflo	4.00	10.50	4.50	30	230 x 230	Nylon skirt, nylon mesh roof
4	Hyperflo	4.00	10.50	4.50	54	137 x 137	Nylon skirt, nylon mesh roof
5	Hyperflo	4.00	10.50	4.50	65	64 x 64	Nylon skirt, Perlon mesh roof
6	Parasonic	4.00	8.00	4.10	25	280 x 280	Nylon skirt, Perlon mesh roof
7	Parasonic	4.00	9.30	3.50	49	230 x 230	Nylon skirt, Perlon mesh roof
8	Parasonic	4.00	9.30	3.50	30	230 x 230	Nylon skirt, nylon mesh roof
9	Parasonic	4.00	9.30	3.50	54	137 x 137	Nylon skirt, nylon mesh roof
10	Parasonic	4.00	9.30	3.50	65	64 x 64	Nylon skirt, Perlon mesh roof
11	Parasonic	5.50	5.30	6.57	260	322 x 353	Nylon skirt, nylon mesh roof
12	Parasonic	5.50	5.30	6.57	260	322 x 353	Nylon skirt, nylon mesh roof
13	Hemisflo	6.00	8.00	5.00	--	--	Solid nylon skirt, nylon ribbon roof
14	Parasonic	4.00	4.60	6.00	320	--	Nylon skirt, 0.25-in. cotton webbing mesh roof
15	Hyperflo	4.00	5.60	7.00	320	--	Nylon skirt, 0.25-in. cotton webbing mesh roof

TABLE II
PARACHUTE TEST CONDITIONS AND RESULTS

							Parachute Stability Characteristics	
Configuration	M_∞	q_∞, psfa	Parachute Nominal Diameter, ft	Canopy Porosity, percent	X, ft	C_{D_o}	Maximum Angle of Oscillation about Base Attachment Point ±deg	Average Frequency of Oscillation About Base Attachment Point, cps
1	3.00	119.8	4.00	8.23	12.5	0.286	6.5	4.0
2	3.00	119.5	4.00	10.50	12.5	0.248	12.0	4.0
3*	3.00	119.7	4.00	10.50	12.5	--	--	--
4	3.00	119.5	4.00	10.50	12.5	0.231	12.5	4.5
5	3.00	120.2	4.00	10.50	12.5	0.261	13.0	4.0
6	3.00	120.2	4.00	8.00	12.5	0.267	4.5	3.0
7	3.00	119.5	4.00	9.30	12.5	0.210	8.0	4.0
8	3.00	119.5	4.00	9.30	12.5	0.250	5.0	3.0
9	3.00	120.3	4.00	9.30	12.5	0.220	12.0	2.5
10	3.00	120.4	4.00	9.30	12.5	0.230	7.5	2.0
11	3.00	120.1	5.50	5.30	12.5	0.229	4.0	2.0
12	3.00	119.5	5.50	5.30	12.5	0.211	14.5	3.5
13	3.00	120.1	6.00	8.00	12.5	0.304	8.5	2.5
14	3.00	120.0	4.00	4.60	12.5	0.262	3.5	4.0
14	2.80	120.0	4.00	4.60	12.5	0.280	2.5	3.5
14	2.60	120.0	4.00	4.60	12.5	0.280	2.5	3.0
15	3.00	120.0	4.00	5.60	12.5	0.285	7.0	3.0

*Failed on deployment

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13 ABSTRACT

Several hyperflo and parasonic parachutes and one hemisflo parachute were tested in the 16-ft supersonic wind tunnel to obtain drag, inflation, and stability characteristics at a nominal Mach number of 3.0 and a nominal free-stream dynamic pressure of 120 psfa. The effects of various types of roof mesh and material on the aerodynamic characteristics of the parachutes were obtained. These data show that the hyperflo parachutes had higher drag loads but less inflation and stability than the corresponding parasonic parachutes with the same combination of roof mesh and material. Differences in roof designs resulted in a drag variation of approximately 25 percent for both the hyperflo and parasonic series of 4-ft nominal diameter parachutes.

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Per AF letter dtd 16 October 1974, Signed William O. Cole

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decelerators						
parachutes						
hyperflo						
hemisflo						
parasonic						
supersonic flow						
wind tunnel tests						
drag characteristics						
static stability						
inflation characteristics						
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